Integrating Models, Measures, and Visualizations of Acoustic Backscatter

John K. Horne
University of Washington, School of Aquatic and Fishery Sciences
Box 355020, Seattle, WA 98115-0070
phone: (206) 221-6890 fax: (206) 221-6939 e-mail: jhorne@u.washington.edu

Award: N00014-00-1-0180

J. Michael Jech
Northeast Fisheries Science Center
166 Water St., Woods Hole, MA 02543
phone: (508) 495-2353 fax: (508) 495-2258 e-mail: michael.jech@noaa.gov

Award: N00014-00-F-0148
http://www.acoustics.washington.edu

LONG-TERM GOAL

The long-term goal of this program is to quantify, understand, and visualize acoustic backscatter from fish. Our strategy integrates numeric backscatter models with computer visualizations and compares model predictions to laboratory and field measurements.

OBJECTIVES

Objectives of this project include: modeling acoustic backscatter from individual and aggregations of fish; integrating fish anatomy, behavior, ontogeny, and physiology in predictions of acoustic backscatter; comparing acoustic technologies used to quantify fish distributions and abundance; and visualizing acoustic backscatter from individual and aggregations of fish.

APPROACH

Kirchhoff-ray mode backscatter models, based on digitized x-ray images of fish bodies and swimbladders, are used to predict species-specific backscatter amplitudes as a function of acoustic wavelength, fish length, and fish orientation (i.e. aspect and roll). Model predictions of backscatter from individuals are also scaled to estimate population backscatter, abundance, and are compared to laboratory and *in situ* field measurements.

WORK COMPLETED

Biological and physical factors influencing fish target strength were identified at an ICES Fisheries Technology Committee study group on target strength estimation in the Baltic Sea. A sampling and backscatter modeling program was designed for Baltic Sea herring and sprat. A fish anesthesia and radiographing protocol was compiled during this meeting to standardize data collection for backscatter modeling.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2002**	2. REPORT TYPE	3. DATES COVERED **00-00-2002 to 00-00-2002**

4. TITLE AND SUBTITLE **Integrating Models, Measures, and Visualizations of Acoustic Backscatter**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of Washington,School of Aquatic and Fishery Sciences,,Box 355020,,Seattle,,WA, 98115**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The long-term goal of this program is to quantify, understand, and visualize acoustic backscatter from fish. Our strategy integrates numeric backscatter models with computer visualizations and compares model predictions to laboratory and field measurements.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**9**	

Four papers and one report were published this year with an additional three papers submitted or in review. A total of 17 presentations were made individually, jointly, or in collaboration with colleagues at regional, national, and international meetings.

East coast

Comparisons of acoustic backscatter measurements of live, individual alewife (Alosa pseudoharengus) to predictions from a Kirchhoff Ray-Mode (KRM) model, a conformal mapping technique, and a modal-series-based deformed cylinder model continue in collaboration with researchers at the Woods Hole Oceanographic Institution. Backscatter measurements were obtained over 360^{o} in the dorsal/ventral and lateral planes using a broadband (40-95 kHz) source. Model results were obtained using digital representations of swimbladder and fish body radiograph images.

A two-week cruise was conducted during Sept. 4-14, 2001 in the Gulf of Maine and Georges Bank regions in collaboration with the Northeast Fisheries Science Center. Dr. Redwood Nero and Charles Thompson (Naval Research Laboratory, Stennis Space Center, MS) conducted low-frequency (0.5-10 kHz) backscatter measurements, and Mr. Gerald Denny (Scientific Fisheries, Inc.) conducted broadband backscatter measurements (100-200 kHz) in conjunction with three downward looking echosounders (12, 38, and 120 kHz).

West coast:

Additional radiographs were obtained and KRM backscatter modeling of juvenile walleye pollock (*Theragra chalcogramma*) was completed to compare ontogenetic changes in acoustic backscatter. Young-of-the-year, juvenile, and adult walleye pollock radiographs were used to quantify the influence of material properties (i.e. sound speeds and density contrasts) on predicted backscatter from fish bodies and swimbladders. A computer-controlled system has been designed and tested to change tilt angles and depths of tethered individual fish. This system will be used to measure backscatter amplitudes and variability of walleye pollock.

Third generation backscatter visualizations were written using object-oriented graphics and the number of features in the viewer was expanded (Figure 1).

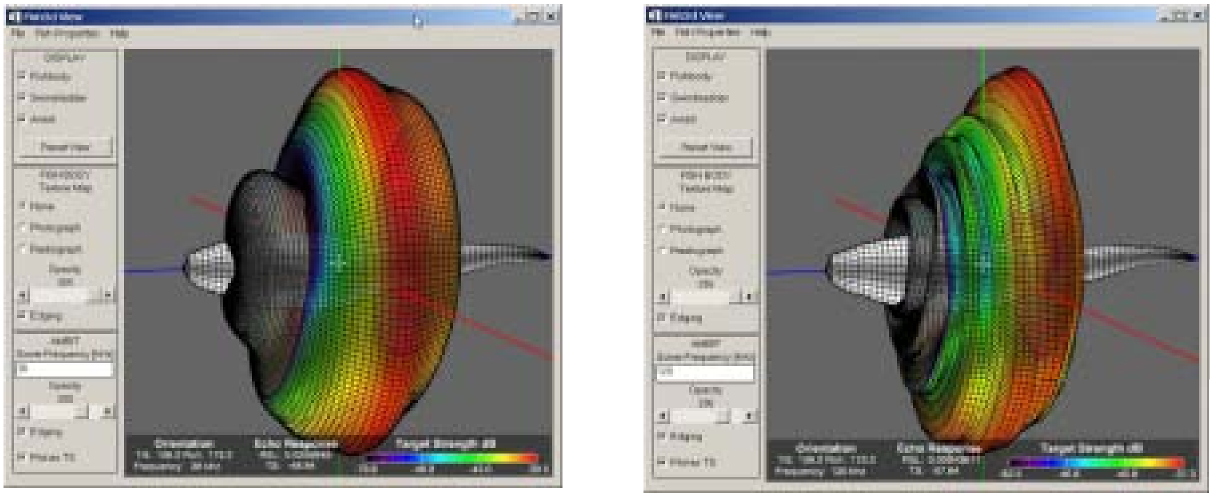

Figure 1. Screen capture of Fish3d viewer showing walleye pollock backscatter ambit in decibel scale at 38 kHz (left panel) and 120 kHz (right panel) with graphic user interface

Backscatter ambits can now be displayed using a logarithmic decibel scale. Visualizations of individual fish backscatter within aggregations were enhanced to include a variety of fish sizes, orientation and backscatter outputs from any fish, and real time color fluctuations to indicate backscatter amplitudes (Figure 2). Defined path or freehand ‘fly-by’ animations can be exported as ‘movie’ files. The Fisheries Acoustics Research website has been updated to include animations (www.acoustics.washington.edu/animations).

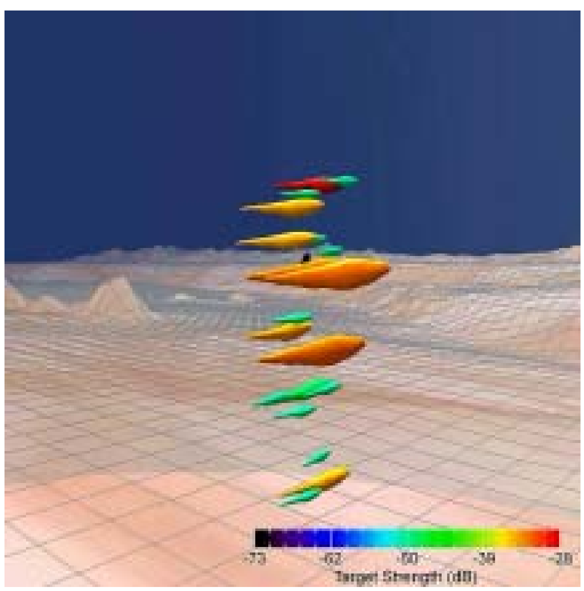

Figure 2. Screen capture of fish schooling animation showing a walleye pollock school in the Bering Sea. Fish bodies are color coded for backscatter amplitude at 38 kHz.

RESULTS

The study group on target strength (TS) estimation in the Baltic Sea defined a general equation that combines the influence of physical (i.e. frequency, temperature, salinity) and biological (i.e. anatomy, behavior, physiology) factors on target strength:

$$\mathrm{TS} = f(\text{frequency}) + f(\text{length}) + f(\text{pressure}) + f(\text{temperature, salinity}) + f(\text{orientation}) + f(\text{activity}) + f(\text{lipid}) + f(\text{gut fullness}) + f(\text{gonad})$$

Having identified individual variables, the next step is to quantify the function and relative importance of each factor using a common currency. Current conversions of target strength to fish length include length, frequency, and limited tilt angle ranges. Quantifying the relative importance will indicate if additional variables should be included in regression models and highlight research areas that will increase accuracy of acoustic-based abundance estimates.

East Coast

Comparisons of acoustic backscatter measurements to KRM model results suggest that KRM model predictions are robust and accurate within 30-40 degrees off dorsal-ventral (Figure 3), and lateral aspects (i.e. broadside incidence) and within the frequency range of the broadband measurements. At aspect angles within 40-50 degrees of head and tail-on orientation, the KRM model tends to predict backscatter amplitudes less than the measured amplitude.

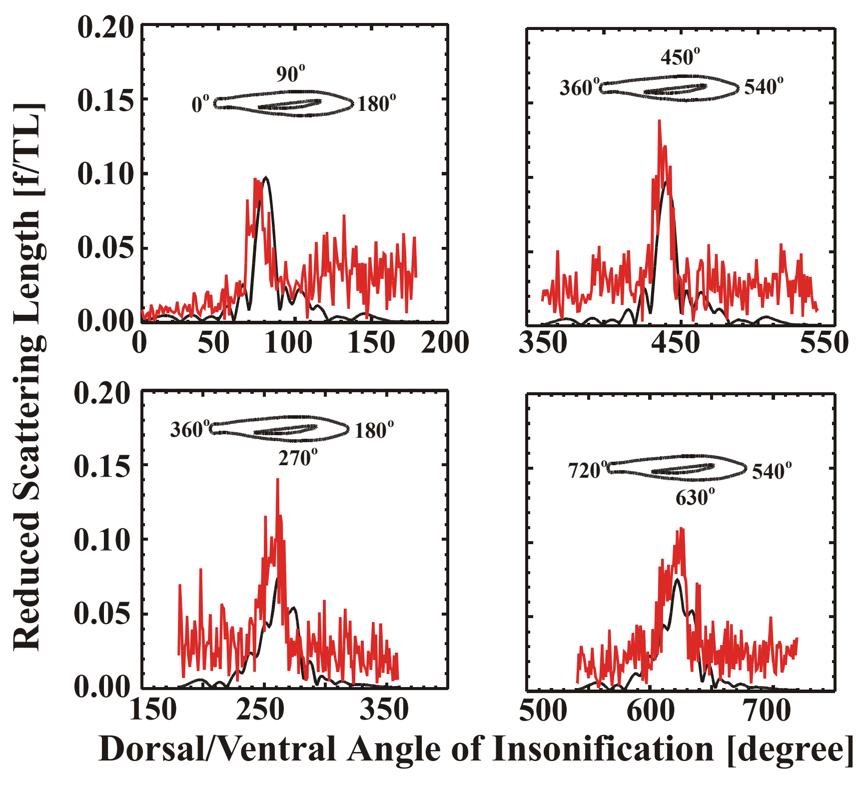

Figure 3. Alewife (length =256 mm) KRM predicted (black) and measured (red) backscatter amplitudes (Reduced Scattering Length) at 50 kHz plotted as a function of dorsal/ventral orientation.

West Coast

Examination of walleye pollock backscatter models, *in situ* target strengths, and a TS-length regression (Figure 4) enabled comparison of numeric and statistical model predictions to empirical measurements.

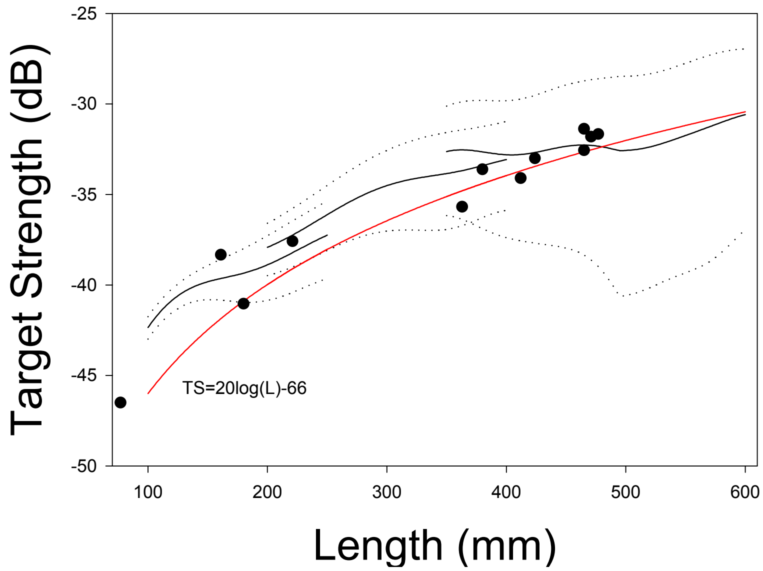

Figure 4. Walleye pollock KRM predicted mean (solid) and one standard deviation (dotted), measured (solid dots), and NMFS TS-length regression (red line) at 38 kHz.

KRM backscatter models of all radiographed fish (n = 35) were used to compile TS – length curves at 38 kHz. The curve is comprised of three overlapping length sections based on young-of-the-year (100 mm – 250 mm), juvenile (200 mm – 400 mm), and adult (350 – 600 mm) life history stages. All but one of the 38 kHz *in situ* average TS values fall within one standard deviation of the KRM predicted TS curve. The fit of the KRM predicted values were also compared to the fit of the National Marine Fisheries Service: $TS=20\log(L_{cm})-66$ regression model. The regression curve, empirical points, and KRM curve are in close agreement at fish lengths greater than 380 mm. The greatest disparity among the three data sources occurs at fish lengths below 200 mm suggesting that additional modeling and measuring of juvenile and young-of-the-year walleye pollock target strength is warranted.

IMPACT/APPLICATIONS

Comparisons of broadband backscatter data to model predictions at a wide variety of insonification angles provide insight to the potential, and the limitations, of obtaining quantitative abundance, length, and biomass estimates from non-traditional acoustic instrumentation such as multi-beam or sector scanning sonar.

Quantifying and ranking the relative importance of biological factors on backscatter amplitude and variability contributes to the discrimination and identification of acoustic targets. Incorporating

anatomical, behavioral, ontogenetic, and physiological variables in target strength models will improve accuracy of fish population abundance estimates.

TRANSITIONS

Researchers in Australia (R. Kloser) and New Zealand (S. McClatchie) are initiating collaborations to compare model predictions to acoustic backscatter measurements of meso- and bathypelagic fish species on commercial fishing grounds off the coasts of the two countries.

RELATED PROJECTS

We are participating in an international study group (Baltic Sea Herring TS) formed by the ICES FAST Working Group to investigate relationships of acoustic backscatter to Atlantic herring and sprat in the Baltic Sea. This study group is using a combination of *in situ* acoustic measurements, biological and morphological measurements, and KRM model predictions to quantify factors that affect target strength in an effort to improve fisheries abundance estimates of these species. The Baltic Sea project provides a base to examine all biological and physical factors influencing acoustic backscatter from teleost fish.

PUBLICATIONS

Arrhenius, F. *et al.* 2001. Report of the Study Group on Target Strength Estimation in the Baltic Sea. ICES CM 2001/B:02 pp. 14.

Horne, J.K. 2000. Acoustic approaches to remote species identification. Fisheries Oceanography 9: 356-371.

Horne, J.K., Walline, P.D. and Jech, J.M. 2000. Comparing acoustic model predictions to *in situ* backscatter measurements of fish with dual-chambered swimbladders. Journal of Fish Biology 56: 57: 1105-1121.

Jech, J.M. and Horne, J.K. 2001. Effects of *in situ* target spatial distributions on acoustic density estimates. ICES Journal of marine Science 58: 123-136.

Mason, D.M., Goyke, A., Brandt, S.B. and Jech, J.M. 2001. Acoustic fish stock assessment in the Laurentian Great Lakes. In: *Great Lakes of the World (GLOW): Food-web, health and integrity*, Ecovision World Monograph Series, M. Munawar and R.E. Hecky (Editors).

Smith, P.E., Horne, J.K. and Schneider, D.C. Life history strategies of anchovy, sardine, and hake in the California Current: comparison of spatial dynamics of the pre-recruit stages. ICES Journal of marine Science (in press).

Jech, J.M. and Horne, J.K. Three-dimensional visualization of fish morphometry and acoustic backscatter. Acoustic Research Letters On-line (in review).

Horne, J.K. Influence of ontogeny, behaviour, and physiology on target strength of Walleye Pollock (*Theragra chalcograma*). ICES Journal of marine Science (submitted).

PRESENTATIONS

Chu, D., Lavery, A. and Jech, J.M. 2001. Inference of size and orientation of swim-bladdered fish from high frequency acoustic echograms. 140 th Meeting of the Acoustical Society of America. Chicago, Illinois.

Horne, J.K. 2001. Incorporating behavior and physiology in acoustic backscatter predictions of walleye pollock. Invited lecture. Hatfield Marine Science Center. Newport, Oregon.

Horne, J.K. 2001. Cod and capelin in the Northwest Atlantic: Ecosystem management that ignored the signals. Invited lecture. University of Washington. Seattle, Washington.

Horne, J.K. and Towler, R.H. 2001. Sensitivity of Kirchhoff-ray mode backscatter predictions to c, g, and h parameter values. ICES Fisheries Acoustics Science and Technology Working Group. Seattle, Washington.

Horne, J.K. and Towler, R.H. 2001. Using backscatter models and visualization to examine fish behavior. ICES Fisheries Acoustics Science and Technology Working Group. Seattle, Washington.

Horne, J.K. and Swartzman, G.L. 2001. The Neptune network: potential fisheries applications. Invited poster. The Oceanographic Society Biennial Scientific Meeting. Miami, Florida.

Horne, J.K., Davis, M., Towler, R.H. and Jech, J.M. 2000. Incorporating behavior in backscatter model predictions of walleye pollock target strength. 140 th Meeting of the Acoustical Society of America. Newport Beach, California.

Jech, J.M. 2001. Innovative uses of Fisheries Acoustics in the Northwest Atlantic. Invited Presentation to International Bioacoustics Conference. Chicago, Illinois.

Jech, J.M. 2000. Recent Innovations in Fisheries Acoustics. Invited lecture. University of Windsor-Great Lakes Institute for Environmental Research, Windsor, Ontario.

Jech, J.M. and Reeder, D.B. 2001. Acoustic broadband backscattering measurements and models of alewife (Alosa pseudoharengus). ICES Fisheries Acoustic Science and Technology Working Group. Seattle, Washington.

Jech, J.M., Reeder, D.B., Stanton, T.K. and Chu, D. 2000. Three dimensional visualization of acoustic backscattering measurements and models by alewife. 140 th Meeting of the Acoustical Society of America. Newport Beach, California.

Michaels, W.L., Demer, D.A. and Jech, J.M. 2001. Acoustical target strength of Atlantic herring using a multifrequency approach. ICES Fisheries Acoustic Science and Technology Working Group. Seattle, Washington.

Michaels, W.L., Jech, J.M. and Demer, D.A. 2000. Multifrequency backscatter measurements of Atlantic herring in the Northwest Atlantic. 140 th Meeting of the Acoustical Society of America. Newport Beach, California.

Reeder, D.B., Jech, J.M., Stanton, T.K. and Chu, D. 2000. Broadband acoustic backscattering from alewife fish—experiment and analysis. 140 th Meeting of the Acoustical Society of America. Newport Beach, California.

Simard, Y., Horne, J.K., Lavoie, D. and McQuinn, I. 2000. Capelin TS: effect of individual fish variability. 140 th Meeting of the Acoustical Society of America. Newport Beach, California.

Swartzman, G.L., Van Holliday, D., Napp, J.M., Horne, J.K. and Winter, A. 2000. Comparisons and evaluation of methods for distinguishing among several functional classes of zooplankton and fish using acoustic backscatter data at four frequencies. 140 th Meeting of the Acoustical Society of America. Newport Beach, California.

Walline, P.D., Horne, J.K. and Hazen, E.L. 2001. Characterizing variation in distributions of Bering Sea walleye pollock. ICES Fisheries Acoustics Science and Technology Working Group. Seattle, Washington.